

# Baryon to Meson Ratios on the Near and Away-Side of Jets and their Centrality Dependence at STAR

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**Abstract.** We measure relative abundances of  $K_S^0$ ,  $\Lambda$  and  $\bar{\Lambda}$  in near-side and away-side cones correlated with triggered high- $p_T$  particles in  $^{197}\text{Au} + ^{197}\text{Au}$  collisions at  $\sqrt{s_{NN}} = 200$  GeV. The centrality dependence of identified particles in the triggered particle cones is also presented. Particle yields and ratios are extracted on the near-side and away-side of the trigger particle. The associate-particle ratios are studied as a function of the angle relative to the trigger particle azimuth  $\Delta\phi$ . Such studies should help elucidate the origin of the modifications in the jet like correlations observed in Au+Au collisions relative to p+p collisions. And these studies also will help understand the variation of local parton densities at the away side. We discuss how these measurements might be related to several scenarios for interactions of fast partons with the medium created in Au+Au collision.

## 1. Introduction

The observation of large collective flows [1, 2] and jet-quenching [4, 7] indicates that a dense medium is created in Au+Au collisions at RHIC [3]. Studies of two particle azimuthal correlations have revealed detailed information about jet interactions with this medium [4, 5, 6]. These measurements can be used to infer properties of the medium such as temperature, density, and viscosity.

In di-hadron correlations from central Au+Au collisions the away-side jet opposing the high  $p_T$  triggered particle disappears [4, 7], while the remnants of the away-side jet are recovered at lower  $p_T$  values [8]. The distribution of these remnants in  $\Delta\phi$  is highly modified in comparison to p+p collisions: the away-side correlation is no longer peaked at  $\Delta\phi = \pi$  but instead has two peaks shifted to either side of  $\pi$  [9]. Several scenarios have been proposed to account for this splitting [10, 11, 12, 13, 14]. And the analysis of three particles correlations is being pursued as one method to differentiate scenarios from jet deflection to cone emission of particles [15, 16].

More information may be obtained about the interaction of fast partons with the medium by studying the particle-type composition of the di-hadron correlations. An increase in the ratio of baryons to mesons has been observed in Au+Au collisions [17]. This increase may depend on the parton density of the system. The coalescence

of constituent quarks has been used to describe successfully much of the observed phenomena. By extension, one might expect a larger baryon-to-meson ratio for intermediate  $p_T$  hadrons on the away-side due to the coalescence of quenched fragments with each other or with constituents from the medium. Studies of the  $p/\pi$  ratio show evidence for such an effect [18].

Information about the relative contribution of quarks and gluons may also be inferred from the antibaryon-to-baryon ratio: the fragmentation of gluon jets yields a larger antibaryon-to-baryon ratio than the fragmentation of quark jets [19]. For this reason, if the splitting of the away-side jet is linked to large-angle gluon radiation, then the antibaryon-to-baryon ratio should increase at angles away from  $\Delta\phi = \pi$ . The presence of these gluons may also contribute to an increase in the baryon-to-meson ratio: a recent study found that the baryon density is largest in collision processes involving gluons (i.e.  $qg$ ,  $gg$ ,  $q\bar{q}g$ , or  $ggg$ ) [20]. For these reasons, measurements of the baryon-to-meson ratio and the antibaryon-to-baryon ratio on the near- and away-side of jets should be useful for understanding the interaction of fast partons with the medium.

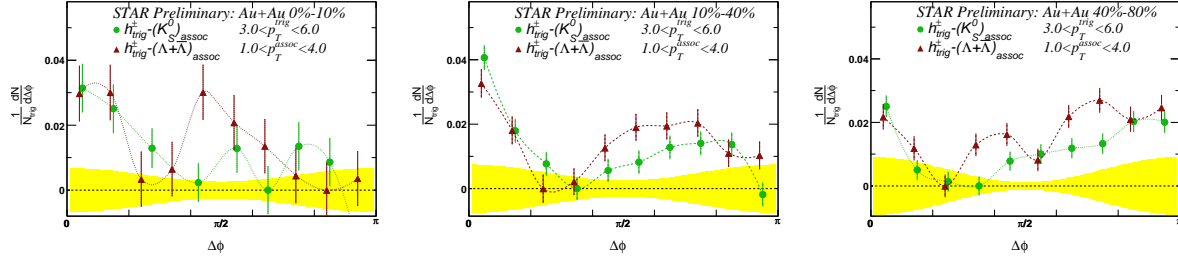
We will present measurements of di-hadron correlations of unidentified trigger hadrons with identified  $K_S^0$ ,  $\Lambda$ , or  $\bar{\Lambda}$  associated partners. For this analysis, a trigger hadron is any charged track with  $3 < p_T < 6$  GeV/c while associated partners are taken from  $1 < p_T < 4$  GeV/c. In the  $|\Delta\eta| < 1$  range, we get the yield  $dN/d\Delta\phi$  for  $K_S^0$ ,  $\Lambda$  and  $\bar{\Lambda}$  as a function of  $\Delta\phi$ . The same procedure is carried out on a mixed event sample to obtain a background distribution used to correct for imperfect detector acceptance.

The  $v_2$  modulated background distribution is subtracted from the corrected  $dN/d\Delta\phi$  distribution by zero-yield at the minimum (ZYAM) [22] or zero-yield at  $\Delta\phi = 1$  (ZYA1). The following form is used to describe the  $v_2$  modulated combinatorial background [1, 22]:  $B(\Delta\phi) = b_0(1 + 2\langle v_2^A \times v_2^B \rangle \cos(2\Delta\phi))$ . The nominal  $v_2$  is taken as the average of  $v_2$  from an event plane analysis ( $v_2\{EP\}$ ) [27] and  $v_2$  from a 4-particle cumulant analysis ( $v_2\{4\}$ ) [23] for the charged hadron or  $v_2$  from the Lee-Yang Zero method analysis ( $v_2\{LYZ\}$ ) [24] for  $K_S^0$ ,  $\Lambda$ , or  $\bar{\Lambda}$  [26, 28]. The difference between  $v_2\{4\}(v_2\{LYZ\})$  and  $v_2\{EP\}$  results and the  $v_2$  fluctuations [25] are considered in the systematic errors.

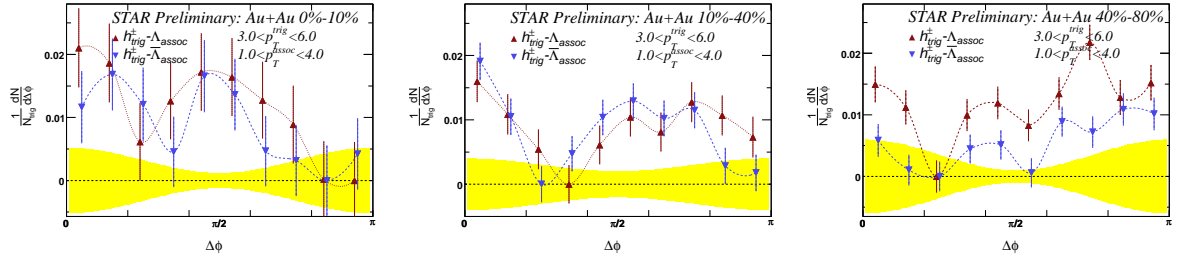
## 2. Results

The acceptance, efficiency, and background subtracted di-hadron  $dN/d\Delta\phi$  distributions are shown in Fig. 1 and Fig. 2. All data are from  $\sqrt{s_{NN}} = 200$  GeV Au+Au collisions. Fig. 1 shows the hadron- $K_S^0$ , and the hadron- $(\Lambda + \bar{\Lambda})$   $dN/d\Delta\phi$  distributions. Fig. 2 shows the hadron- $\Lambda$  and hadron- $\bar{\Lambda}$  correlations separately. From the left to right, the plots show the central to peripheral collision. For all particle combinations a strong correlation is seen on the near-side of the charged hadron trigger ( $\Delta\phi < 1.1$ ) as would be expected from fragmentation of a fast parton or jet. The correlation structure on the away-side of the trigger hadron changes with the collision centrality. From the central to peripheral, the away-side shows a double bump, broadened and a single peak. This is consistent

with the di-hadron distributions from STAR [21]. In the central collision, the away-sides exhibit a minimum at  $\Delta\phi = \pi$  where typically a maximum would exist. These features are similar to those already observed for unidentified di-hadron distributions which have much better statistics [22]. We extract the conditional yields of identified  $K_S^0$ ,  $\Lambda$  and  $\bar{\Lambda}$  particles on the near-side ( $0. < \Delta\phi < 0.35\pi$ ) and away-side ( $0.35\pi < \Delta\phi < \pi$ ) of the trigger hadron.

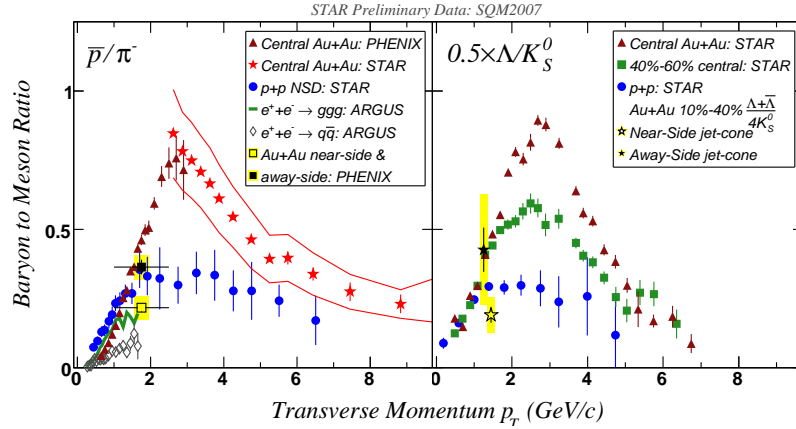


**Figure 1.** Hadron- $K_S^0$ ,  $-\Lambda+\bar{\Lambda}$  correlation function from central to peripheral collision in  $^{197}\text{Au} + ^{197}\text{Au}$  collisions at  $\sqrt{s_{NN}} = 200$  GeV. The trigger particles  $p_T$  range is  $3.0 < p_T < 6.0$ ; the associate  $K_S^0$ ,  $\Lambda$ , or  $\bar{\Lambda}$  particles  $p_T$  range is  $1.0 < p_T < 4.0$ . The yellow band around the zero is the systematic errors.



**Figure 2.** Hadron- $\Lambda$ ,  $-\bar{\Lambda}$  correlation function from central to peripheral collision in  $^{197}\text{Au} + ^{197}\text{Au}$  collisions at  $\sqrt{s_{NN}} = 200$  GeV. The trigger particles  $p_T$  range is  $3.0 < p_T < 6.0$ ; the associate  $\Lambda$ , or  $\bar{\Lambda}$  particles  $p_T$  range is  $1.0 < p_T < 4.0$ . The yellow band around the zero is the systematic errors.

In Fig. 3 we compare our results for the  $(\Lambda + \bar{\Lambda})/K_S^0$  ratio to other measurements of the baryon-to-meson ratio. The left panel shows the  $\bar{p}/\pi^-$  ratio measured in  $e^+ + e^-$  [29], p+p [30], and  $Au + Au$  [18, 31] collisions (these measurements are not conditional yields). The right panel shows the  $\Lambda/K_S^0$  ratio for p+p, mid-peripheral  $Au + Au$  [32], and central  $Au + Au$  collisions scaled by 0.5. The measurements of the  $\bar{p}/\pi^-$  ratio made for particles associated with a trigger hadron ( $p_T > 2.5$ ) from PHENIX are also shown in the left panel while our results are shown in the right panel. We find that both STAR and PHENIX measurements are consistent with a larger baryon-to-meson ratio on the away-side than on the near-side. In addition, on the near-side the baryon-to-meson ratio is closer to values measured in p+p collisions while on the away-side the ratio is closer to that measured in central or mid-central  $Au + Au$  collisions. This observation may indicate that the larger parton density of matter is traversed by the away-side jet.

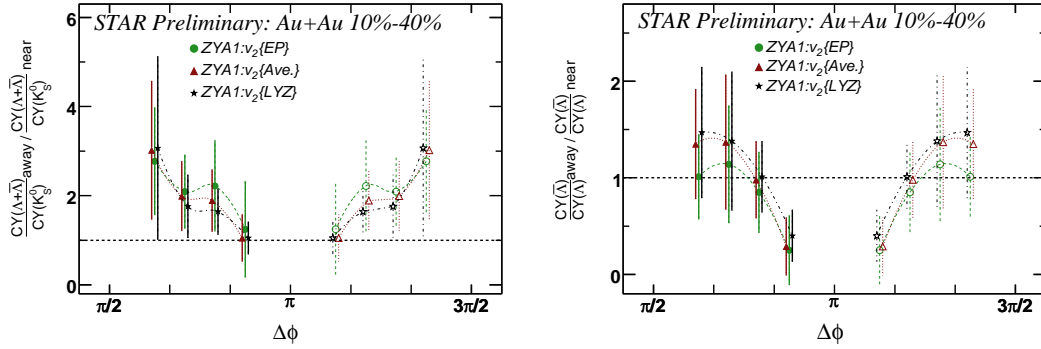


**Figure 3.** Left panel:  $\bar{p}$  to  $\pi^-$  ratio at the mid-rapidity for central Au+Au and p+p collisions at 200 GeV. The measurement of the proton to pion ratio for particles associated with a trigger hadron ( $p_T > 2.5$ ) is also shown. Right panel:  $\Lambda$  to  $K_S^0$  ratio in central Au+Au, mid-peripheral Au+Au and minimum-bias p+p collisions. The measurement of the  $\Lambda$  to  $K_S^0$  ratio for particles associated with a trigger hadron ( $p_T > 3.0$ ) is shown. Values are scaled by 0.5. In the plots, the yellow band is the systematic errors.

This larger parton density may lead to an enhancement in baryon production. Such an effect is expected if the baryon enhancement in the intermediate  $p_T$  region observed in Au+Au collisions is due to multi-parton interactions such as gluon junction [33] or quark coalescence [34].

More information can be obtained from the distributions in Fig. 1 and Fig. 2 by examining how the ratios depend on  $\Delta\phi$ : *e.g.* the ratios of the conditional yields on the away-side can help us better understand the source of the correlations that appear at large angles away from  $\Delta\phi = \pi$ . It has been speculated that the enhanced correlations at wide angles may be related to large angle gluon radiation [13, 35], deflection of the away-side jet by the flowing medium [12], or a shock wave that is induced in the medium by a fast moving parton [10, 11]. We expect the dependence of the particle ratios on  $\Delta\phi$  to differ in the three above scenarios: *e.g.* gluons radiated at large angles may lead to a larger antibaryon-to-baryon ratio in that region. A recent study also found that the presence of these gluons may also lead to an enhanced baryon-to-meson ratio [20]. Alternatively, the higher density that would be associated with a shock-wave could lead to an increase in the baryon-to-meson ratio via coalescence of co-moving partons. It has also been argued that since a shock wave should be moving at the speed of sound in the medium, the particles produced from such a shock should not be very fast particles. For a slow particle to satisfy the  $p_T$  cut in our analysis it would have to be massive. For this reason, one might expect the correlation at large angles to have a larger number of massive particles and consequently a larger baryon-to-meson ratio. Detailed calculations of particle ratios from the above scenarios have not been made but are being pursued by us.

Fig. 4 shows the particle ratios (ratios of the conditional yields) on the away-side



**Figure 4.** Left panel: The baryon-to-meson ratio on the away-side vs.  $\Delta\phi$  scaled by the same ratio in the near-side jet-cone. Data are for 10% – 40% Au+Au collisions at 200 GeV. This double ratio appears to be insensitive to the background subtraction method. Right panel: the same for  $\bar{\Lambda}/\Lambda$ .

as a function of  $\Delta\phi$ . The ratios are normalized by the corresponding ratio measured in the near-side jet-cone so that unity corresponds to the case where the away-side particle composition is the same as that in the near-side jet cone. We find that this double ratio is largely independent of the elliptic flow used in the background subtraction indicating that such an analysis is able to reduce systematic uncertainties. The left panel shows the baryon-to-meson, awayside-to-nearside double ratio and the right panel shows the antibaryon-to-baryon, awayside-to-nearside double ratio. In both cases the data from  $\Delta\phi < \pi$  (closed symbols) has been reflected to  $\Delta\phi > \pi$  (open symbols). The uncertainty on both measurements remains large and precludes strong conclusions about the shape or magnitude of the ratios. We observe some indication that the  $(\bar{\Lambda} + \Lambda)/K_S^0$  ratios may be large at around  $\Delta\phi = \pi/2$  than they are at  $\Delta\phi = \pi$ . This may be consistent, for example, with the increase of the parton density at large angles as discussed above.

### 3. Summary

We measured di-hadron azimuthal angle correlations in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. Charged hadrons ( $3.0 < p_T < 6.0$  GeV/c) are used as the trigger particle;  $K_S^0$ s,  $\Lambda$ s and  $\bar{\Lambda}$ s ( $1.0 < p_T < 4.0$  GeV/c) are used as the associated particles. We extracted the conditional yields of identified associate particles on the near- and away-side of the jet trigger and calculated the near and away-side particle ratios. The systematic uncertainty from  $v_2$  and the background normalization are large. These uncertainties can be reduced with more data to reduce the error on the level of the background and a better understanding of  $v_2$  to reduce uncertainty on the shape of the background. Both STAR and PHENIX results are consistent with a larger baryon-to-meson ratio on the away-side than the near-side. We studied the shape of away-side particle ratios and find that this shape is insensitive to several sources of systematic uncertainty. Our measurements are consistent with the physical picture that the parton density may be higher at large angles away from  $\Delta\phi = \pi$ . These measurements should help elucidate

how fast partons interact with the matter created in Au+Au collisions at RHIC.

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